# DETECTION TECHNIQUES FOR TENUOUS PLANETARY ATMOSPHERES

Twenty-Fifth Six-Month Report
for the period
1 July 1975 to 31 December 1975

for the

National Aeronautics and Space Administration
Grant NGL-03-002-019

**(NASA-CR-146114) DETECTION TECHNIQUES FOR TENUOUS PLANETARY ATMCSPHERES Progress Report, 1 Jul. - 31 Dec. 1975 (Arizona Univ., Tucson.) 45 p**

**N76-71372**

**Unclas**
**00/98 08588**

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## INTRODUCTION, ABSTRACT, AND SUMMARY

This report will cover the work performed from 1 July 1975 through 31 December 1975 on Grant NGL 03-002-019 between the University of Arizona and the National Aeronautics and Space Administration.

This contract was set up to support the development of new types of detectors for analysis of planetary atmospheres. Initially, the interest was in detectors for use under partial vacuum conditions; recently, the program has been extended to include detectors for use at one atmosphere and adsorption systems for control and separation of gases.

Results to date have included detectors for $O_2$ and $H_2$ under partial vacuum conditions (Publications 1, 3, 4). Experiments on detectors for use at high pressures began in 1966; and systems for CO, $H_2$ and $O_2$ were reported in 1967 and 1968 (Publications 8, 11). In 1968 studies began on an electrically controlled adsorbent. It was demonstrated that under proper conditions a thin film of semiconductor material could be electrically cycled to adsorb and desorb a specific gas. This work was extended to obtain quantitative data on the use of semiconductors as controllable adsorbents (Publications 11, 12).

In 1968 a new technique for dry replication and measurement of the thickness of thin films was developed. A commercial material, Press-O-Film, was shown to be satisfactory when properly used. This technique is most useful for studies of semiconductor thin films where normal interference techniques are not practical because of the non-reflective nature of the film (Publication 13).

During the period from 1968 through 1971 the Carbon Monoxide Detector, first demonstrated on the NASA program (Publication 8), was refined and improved for use by the Department of Health, Education and Welfare.

In 1969 studies began on a Corona Discharge Detector for water vapor. This system was shown to be rapid in response, suitable for continuous operation, and reasonably linear in output (on a logarithmic plot) from 10 percent relative humidity to 95 percent relative humidity. A program to develop this detector for hydrological applications began in 1970 but was temporarily dropped because of limited user interest.

In 1970 we began an investigation of the catalytic oxidation of various gases. i.e., CO, $NH_3$ and $H_2$ over metallic catalysts. We demonstrated that the rate of reaction could be observed and controlled in terms of the exoelectron emission from the catalysts (Publication 16). In 1971 this study was directed to the expanded monel metal catalysts used for auto exhaust emission control and for spacecraft atmospheric purification (Publication 20).

This investigation has been extended to catalysts operating at ambient (one atmosphere) pressure and to the dispersed metal-ceramic catalysts used in the chemical industry. There seems to be no question that the exoelectron effect can be used to monitor catalyst operation.

The capability of monitoring the actual rate of catalysis is important in many industrial operations where a slight change in rate-of-reaction can have a significant effect on the safety or economics of the process. The conventional techniques, which involve analysis of the reactant or temperature control of the catalyst, are frequently too slow to permit accurate control. Application of this control technique has been discussed with the Dow Chemical Company (Texas Division). Another application of the exoelectron effect exists in the area of catalyst research. An understanding of the mechanism relating catalysis to electron emission will help in obtaining a final explanation for the catalytic process itself.

In 1971 we began the study of a new technique for analysis of solid materials. This system involved heating or grinding the substance and observing the induced exoelectron emission. The effect is known as Temperature Stimulated Exoelectron Emission (TSEE). One application of this phenomenon to observation of grinding processes has been published (Publication 18).

In 1973-74 we began investigating the electrostatic charging phenomena that are associated with the generation of dust particles. These charge effects may be an important factor in the atmospheric suspension of particulates during dust storms. This may be particularly significant in the Martian dust storms where the irregular Martian surface would almost preclude the usual wind-dust mechanism.

We have demonstrated that naturally occuring dusts acquire electrostatic charges when agitated. These charged particles are "levitated" by the planetary electrostatic field and become "permanent atmospheric impurities". If similar conditions exist on Mars the electrostatic effects might be the mechanism for suspension of vast quantities of dust in the "thin" Martian atmosphere.

Other aspects of this dust investigation relate to an understanding of dust levitation on the moon. Recent lunar observations suggest that a significant amount of moving dust is associated with the solar terminator. This dust suspension can only be understood in terms of electrostatic phenomena. An additional problem in understanding the lunar dust studies is the obvious lack of any "wind" to raise the dust. It has been suggested that sand slides or thermally induced rock splitting might provide enough electrostatic charging to induce dust levitation. To investigate this question we began, in 1975, a study of electrostatic charging of minerals under stress. Another facet of this study was aimed at an analysis of the charging of sand as sliding occurred. This work is continuing; partial support for the rock studies has been obtained from the National Science Foundation. The NSF interest relates to the pre-failure detection of underground rock bursts.

Another application of the dust charging studies is aimed at the control of respirable industrial dust by exposure to oppositely charged water fog. This system is being tested at several industrial plants and the indications are that it is a practical dust control technique. The commercial aspect of this work will be handled by a mid-western corporation. This is an example of a practical fall-out from the Space Program.

# SUMMARY OF WORK IN THE PAST SIX MONTHS AND STUDIES PLANNED FOR THE NEXT REPORT PERIOD

## Electrostatic Effects in Minerals Under Stress

The mechanism of ceramic failure is reasonably well understood; fracture involves either tension or shear loading (1). Many studies (2) have indicated that failure is preceded by acoustic noises generated by microfracture. There have been other reports (3), dating back to 1500 A.D., of electrical phenomena associated with rock failure, but to date no mechanism for these effects has been established.

One obvious mechanism would involve piezoelectric effects, though it is difficult to imagine just how such phenomena could arise in a material as non-uniform as rock. Parmenhenko (4) has discussed electrostatic effects in rock materials and cites a number of experiments that suggest the existence of piezoelectric charging in many different types of rock. Another mechanism, involving the stress induced diffusion of sodium ions, has been reported by Weber and Goldstein (5). This system was shown to operate in plate glass but there have been no reports of similar experiments in other ceramics. Resistivity changes, in rocks under stress, have been discussed by Brace and Orange (6), but their mechanism does not predict electrostatic charging. In view of the lack of agreement among these investigators we decided to build a test system to evaluate rock electrification processes under various conditions.

In general, there seems to be no argument that load related changes in resistivity and electric charge occur, but the question of why remains unanswered. The problem is made more complex by the report of Wollbrandt, et al (7) indicating that high energy (100 kev) electrons are emitted by alkali halide crystals during fracture. If similar effects occur in rock (evidence for this will be cited below) any suggested mechanism must allow for the generation of electrons with energies up to 100 kev. All of the above suggests that investigation of ceramic electrostatic effects will be a difficult and rewarding problem.

## LABORATORY STUDIES

The first part of this program was devoted to a study of the electron-ion emission from rocks and ceramic materials under stress. This work indicated that such emission occurs and that the electron-ion currents can be correlated with the load on the material. The observation of light flashes during fracture suggested the emission of high energy electrons that could "excite" air molecules which then decay by a photon mechanism.

The second phase of the program, which is currently under way, was devoted to measurements of the electrical currents produced by the rock or ceramic as a function of load. It was hoped that measurement of these currents would allow us to understand the mechanism(s) and design a system for prediction of rock failure.

# EXPERIMENTAL SYSTEM

The system was designed* around a loading frame and a twelve ton hydraulic jack driven by air over oil hydraulic intensifier. The loading system and two typical experimental setups are shown in Figure 1. Under compression loads the rock fails in a combination of tension and shear. In the bending mode, failure is due to pure tension.

The experimental materials available included various types of glass, provided by Mr. Richard Sumner of the University's Optical Science Laboratory. Rock specimens were made available by the University of Arizona College of Mines and Mr. Vern Hooker of the United States Bureau of Mines, Denver Laboratory. Coal specimens were provided by Mr. W. J. Vincinelly of the State of Pennsylvania, Bureau of Deep Mine Research and by Mr. John Kistner of Northumberland, Pennsylvania. All of this assistance is gratefully acknoqledged.

Electrical contact to the specimens was made in a variety of ways. On glass and hard rock we ground indium into the surface with a small hand grinder. (The grinding wheel was "loaded" with indium and then pressed against the rock.) Soft solder was used to attach wires to the indium, in some cases both indium and Aquadag were used to make contact over a larger area.

The indium grinding process may produce a defect in the surface that can serve as a "stress raiser." When this was a problem, simple

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*The system and loading fixtures were designed and constructed by Mr. Christian W. Savitz.

spring contacts and silver paint (General Cement) or Aquadag (Acheson Colloids, Inc.) were used. In soft rock or coal it was possible to drive-in steel phonograph needles and solder wires to the needles.

We must note that none of the above contact techniques are thought to be truly "ohmic" in the sense of freedom from blocking and rectifying effects. However, we suggest that detection of load changes and pre-fracture effects is practical even with non-ohmic contacts. We would hope to develop a general technique for producing ohmic contacts on rock but this may not be accomplished under the present program.

## EXPERIMENTAL RESULTS

### A. Compression Loading of Rock Cores

The first studies involved compression loading of rock cores in the apparatus of Figure 1. In earlier studies we had observed significant emission of both electrons and ions as Pyrex tubes or rock cores were loaded to failure. Typical data of this type is shown in Figure 2 where the electron-ion currents were measured by metal rings spaced some 10 mm from the Pyrex cylinder. Similar data on the mineral andesite is shown in Figure 3. Here only electron currents were measured but the data and correlations are quite similar to those of Figure 2.

In the present studies the probes were placed in contact with the rock itself, with the expectation of demonstrating that it was possible to detect stress related electrostatically generated currents. The tests with rock cores were performed with the hope of simulating the actual failure situation observed in a rock burst. However, this type of experiment is well known to suffer severe difficulty because of complex platen-specimen interactions. To reduce the hazard of fracture beginning at the platen-specimen interface, we installed stainless steel hose clamps, as reinforcements, at the ends of the core. These clamped areas were expected to be under a lower stress than the center of the specimen (because of the clamps) and were used as "reference" contact points. We suggest that these results represent the electrical effects observed in a "stressed" and relatively "nonstressed" region.

Typical data of this type is shown in Figures 4, 5, 6, and 7. In Figure 4 the spikes on the current signals from the center region (test contact) and the clamped area (reference contact) are well correlated with the changes in load. The amplitude of the test contact signal is significantly larger than the reference contact signal, as would be expected. There was some localized crushing in the reference contact area and this may account for the observed reference contact signals. The sign reversal of the test contact signal observed at 4.5 minutes, has been seen with a number of granite type materials and is usually taken as an indication that failure is imminent. More data of this type will be discussed below.

Similar results, on limestone, are shown in Figure 5. Here there was no crushing, in the reference contact area of the specimen, and the reference contact signal showed no change. The test contact signal did not show the spikes observed with granite, instead there was a change in the sign of the signal and a steady increase with load, to failure.

Other data, on a granite material, is shown in Figure 6. Here again there was no failure in the reference contact area and the current signal from that region was essentially constant. The signal from the test contact region increased in a series of steps as the load changed, the correlation between the increases in load and the current changes is obvious. It was interesting to note that, with this material, the current did not decay back to the base line with time. In one test (not shown) the load was maintained for over five minutes but the current level only fell some 20% below the peak value attained when the load was applied.

The last experiment in this series was designed to determine if the signal from the failure area could be detected at some distance from the point of failure. The converse question would be, "is the signal from the failure area larger than that from an adjacent region?" The data here is shown in Figure 7, failure began at or near the upper contact with limited crushing near the lower contact. This can be seen in the current signals, initially the lower contact signal was the larger of the two but as the load increased the upper contact signal exceeded that from the lower contact. This suggests that the point of failure will produce the largest signal, which is what one would hope.

The decay of the current spikes with time presents a different picture, normally the signal spikes from Texas granite decay very rapidly and this was observed at the failure area. However, the signal away from the failure region decayed much more slowly, we have no explanation for this at the moment.

B. Rock Slabs Under Bending Stress

One difficulty with the rock core tests is that the stress distribution in the rock is quite complex with no clearly delineated areas of tension and compression. The loading of flat slabs, with the apparatus shown in Figure 1 presents an entirely different picture. Here the upper surface is in pure tension while the lower surface is in compression. In this case the usual stress-strain formulas can be used to calculate the loads and deflection involved.

Typical results with this type of experiment are shown in Figures 8 through 17. The data of Figures 8 through 15 was taken on Texas granite because of its history of violent fracture in earlier loading tests. It was thought to be typical of the rocks found in areas prone to sudden failure.

In Figures 8, 9, and 10 we see that the current spikes from the upper (tension) side of the slab are positive while the signals from the lower (compression) side are negative. This agrees with the Weber-Goldstein theory (Reference 5) which suggests that differential charging is due to stress induced diffusion of sodium ions.

Unfortunately this theory meets with difficulty when we note that the pulses generated by changes in load die away rather quickly in spite of a constant load. Another difficulty with the Weber-Goldstein mechanism is the existence of test data (to be discussed below) in which the pulses from the upper (tension) side are negative while those from the lower (compression) side are positive. There is some suggestion that a contact blocking or rock impurity phenomena is responsible for this reversal but in any case the transient nature of the current pulses suggests a piezoelectric mechanism. (The dying away of the pulses would be due to the current drawn from the specimen.) In a later series of experiments, we hope to use a non-contacting, high impedance, voltage detector to determine the meachnism of the charge generating effect.

Turning again to Figure 8, it is interesting to note that before failure (at the seven minute point) a reversal of the lower side current occurs. There is also some evidence that the pre-fracture lower side currents do not die away as long as the load is held constant and this may prove useful as an indicator of imminent specimen failure. The data of Figure 9 is essentially a duplicate run of Figure 8, we wished to see how repeatable the phenomena really was. It is apparent that all the features discussed for Figure 8 are present in Figure 9 suggesting that the effects involved are repeatable.

In the tests of Figures 8 and 9 we wished to see what currents if any were generated in areas of essentially zero stress. A reference contact was attached at the end of the specimen and showed no-change during the test.

Other data on red granite is shown in Figure 10 - for three runs on a single specimen. The load was released at the end of the first two tests, on the third test the specimen was taken to failure. All three runs displayed very similar features including a significant increase in upper and lower contact urrent with load. This increase was in addition to the spikes usually observed with this material and can serve as an example of the various types of electrical phenomena observed with a single material. It is tempting to suggest that at high stress levels the piezoelectric effect is overwhelmed by the charge diffusion phenomena of Weber and Goldstein, but at this point we do not have enough data to even suggest a mechanism.

The data of Figures 11 and 12 are in distinct contrast to the previous results in that the currents from the lower contact are positive while those from the upper contact are negative. This may be due to some blocking contact effect or a change in moisture contact of the rocks. We notice that in Figures 11 and 12 there were significant changes in the steady state signal level before failure. This is usually taken as an indication that failure is imminent.

Figure 13 shows similar results obtained with pin contacts inserted into drilled holes. This suggests that the changes in sign observed in Figures 11 and 12 are more likely to be a function of the rock rather than the method of contacting the rock.

All of the above data was taken on "dry" rocks stored in the laboratory for several months. The next experiment was designed, to determine the effects, if any, of water saturation on the current signals generated during loading. Several specimens were soaked in distilled water for 100 hours before testing. For the test the rock was dried by rubbing with a paper towel to remove surface water. The first data is shown in Figure 14, the current levels were significantly higher and there was a steady state current that did not decay as long as the load was applied. Other than that the gross features of the Figure appear to be quite similar to those observed with dry rocks of the same type. This suggests that the Rock Burst Detection System will be able to operate even with "wet" rocks.

Data on a limited number of other materials has been obtained to determine if the currents observed with red granite are unique to that material. Typical results on dry galena quartz are shown in Figure 15. This data was taken early in the program and there was no lower side electrical contact. The reference contact was not placed in a truly sttess-free area and there was some signal from the reference contact as the load level changed. Nevertheless, the upper contact signal does display many of the features observed with red granite. There are significant spikes associated with changes in load and a steady state current that does not decay to zero in the presence of constant load. The sudden variations in signal level, at constant load, may be associated with micro-fracture phenomena but at present this is only supposition.

In Figure 16 we show some of the early data taken on dry sandstone. Here again we see the spikes that we have come to associate with changes in load but there is also a steady increase in signal level, with load (that shows no sign of decay at constant load). This may well represent a significant difference between the igneous, granitic rocks that might be expected to display piezoelectric phenomena and the sedimentary rocks that are unlikely to have piezoelectric characteristics.

## PLANS FOR THE NEXT SIX MONTH PERIOD

In the next six month period we plan to continue the measurements of electrical currents from rock or ceramic materials under stress. These tests will include coal and coal shale materials and rocks that have been saturated with water. Many mines are quite wet and the effects of absorbed water must be determined.

The electrostatic charging, if any, will be measured by a non-contacting Trek electrostatic voltmeter. We suspect that ejection of fine particulate matter occurs during the pre-fracture phase and we hope to detect these particles by means of greased microscope slides.

The laboratory studies of ceramic failure will be extended to a more detailed measurement of the energies of the ions and electrons emitted by rocks under stress. This will involve a 50 ton press, which is being assembled, and a liquid scintillator-photon counter system. This system will be complex and expensive but there seems to be no other way to do the experiment. Rock fracture and spalling would destroy the usual thin window geiger counters or surface barrier detectors. The liquid medium can be expected to respond to the electron-ion currents and to stop flying rock fragments. The liquid will have to be pumped and filtered after every experiment but the information to be obtained is judged worth the effort.

### Electrostatic Effects Associated with Sand Dunes and Moving Particulate Matter

In earlier studies it was demonstrated that particulates of respiratory size acquired a charge when ground or agitated. In most cases the charge was negative and we suggested that this negatively charged material might interact with the earth's electrostatic field to levitate the particles. We consider that this type of levitation has been demonstrated but as yet no mechanism for the initial raising of the particles has been proposed. On earth or even on Mars one might postulate that the dust is raised by local winds, but this cannot possibly be the case on the moon. Even on Mars the suggestion of local winds as a dust raising mechanism is difficult because of the irregular Martian topography.

In view of the above and the knowledge that electrostatic effects had been observed in sand dunes we suggested that the initial levitation process might involve the charging-up of a sand dune, this dune would then eject any particles having the charge of the same sign as the dune itself. One might even suppose that a charged dune could eject small particles with enough energy to rise several centimeters, this would permit any local winds to effectively keep the particles suspended. A search of the literature revealed numerous references to the charging of sand as it is windblown or flows down a slope (8). No general explanation for this effect has been given but the process seems to depend very strongly upon the absence of water vapor--a condition that is easily satisfied on the moon or Mars.

Under natural conditions sand is usually found in dues or rows of sand waves. No measurements of sand dune electrostatics have been found in our literature search but there are publications that "suggest" the presence of electrostatic phenomena under "dry" conditions. (We were referred to this data by Dr. David Criswell of the NASA Lunar Science Center in Houston; his assistance is gratefully acknowledged.) Typical references of this type are 9, 10 and 11 relating to the so called "booming or singing" dunes. It seems that under dry conditions these dunes generate acoustic noise (50 to 300 Hz) when the sand is moved. In some cases the noises are loud enough to be heard at a distance of 1500 meters. The sound is not a broad spectrum signal but is sharply peaked at specific frequencies.

In Reference 9 some crude observations (sand grains clinging together in strings, attachment of sand grains to glass, etc.) indicated the presence of electrostatic effects. In references 10 and 11 some indication of electrostatic effects existed but no numerical measurements were made. It is interesting to note that the boom sands of the Kalihari are very deficient in "fines" smaller than 150 mesh (0.1 mm) when compared to non-booming sand. It may well be that the fines have been ejected by electrostatic repulsion and carried away by the wind. This would agree with suggested levitation mechanism discussed above. Unfortunately this "deficit fines" was not observed in the booming sand studies of References 10 and 11. It may well be that the older dunes of the Kalihari have ejected the fine particulates while the younger dunes in Nevada have not. In any case we cannot suggest that the presence or absence of fines is related to the "boom sands". It seems more reasonable to relate booming to electrostatic effects of some unknown character. More experimental studies will be needed to correlate electrostatic and acoustic phenomena. To date this has not even been attempted in the laboratory to say nothing of the field.

In view of the apparent lack of in-the-field experimental studies we decided to first simulate the phenomena in the laboratory and develop laboratory measurement techniques that might be moved into the field at some future date. Once again a search of the literature indicated that no apparatus for this type of experiment had been reported and we decided to build three small experimental systems.

The first system, which is shown in Figure 17, was designed to lift sand and deposit it to form a dune. The Trek electrostatic probe shown in Figure 18 was to be used for observation of the surface charge of the dune and for monitoring discharges as the dune was allowed to "slip" to a new angle of repose. The first studies with this system indicated that a dune could be constructed and that the dune acquired a charge as the sand built up. A microphone pickup was buried in the dune to detect booming as the dune was pushed over, but no signals were observed. We speculate that the relative humidity in the laboratory (30%) was too high and plan to repeat the experiment with "dry" air.

An interim system, to investigate the effect of a partial vacuum, was designed around a 1000 ml boiling flask and a rotary evaporator of the type used in chemical laboratories, Figure 19. Boom Sand from Fallon, Nevada was loaded into the flask, the microphone pickup was attached to the fixed part of the rotation system and a mechanical vacuum pump was used to evacuate the flask. External heat was provided by a laboratory hair dryer.

The somewhat limited results, to date, indicate that both heat and vacuum are necessary before any acoustic signals, above the random noise level, are generated. The vacuum may serve primarily as a mechanism for getting the water out of the sand since the sand continued to "boom" for some minutes after the pump had been shut off and the flask backfilled with room air. If room air was used, continuous heat from the hair dryer was necessary; we suggest that the hot sand does not readily absorb water vapor.

In the next series of experiments the flask will be backfilled with dry air in the hope of maintaining the boom characteristics even when the jar has cooled to room temperature. The fact that booming was observed under partial vacuum conditions suggests that trapped air is not a part of the boom mechanism. It seems more reasonable to propose that the vacuum removes water and that this dry condition encourages electrostatic phenomena. More details on this will be available in our next report.

The other experimental system shown in Figure 19 was built around a tumbler of the type used for polishing by rock hounds. The addition of internal lifter bars allowed the tumbler to lift sand. The acoustic noises were detected by a microphone crystal and there were provisions for external heat and flushing with dry air. The results of some very limited experiments indicate that booming occurs once the sand has been dried and that the sand continues to boom as long as moisture is kept out of the system. Some electrostatic effects, associated with the acoustic noises, have been observed and we hope to correlate these two phenomena. Acoustic analysis equipment is available in the University Speech Department and we expect to use their system to determine the amplitude-frequency spectrum.

These systems will be valuable as we develop equipment that can be used for field studies of booming dunes. Ultimately we would hope to show that dunes can acquire large electrostatic charges and eject small particulates.

Surface Catalysis and Exoelectron Emission

This program is an outgrowth of our earlier studies of gas-surface interactions with the mass spectrometer. We have shown that as soon as catalytic oxidation of CO, $H_2$ or $NH_3$ begins (on hot platinum), there is emission of nonthermal exoelectrons. This "exoelectron" emission can be used to monitor the rate of catalysis. Suppression or enhancement of this exoelectron emission results in an increase or decrease in the rate of catalysis itself. A paper on this topic has appeared in the Journal of Catalysis (see Publication 16).

In another study we followed the catalytic reaction of NO with CO over hot monel. Monel is the candidate metal for a reaction to remove $NO_x$ from automotive exhaust gases, and we have demonstrated that the rate of reaction can be monitored in terms of exoelectrons emitted by the catalyst. A short paper discussing our results has appeared in the Journal of the Society of Automotive Engineers (Publication 19).

In a more recent work we observed exoelectron emission associated with the oxidation of CO and $CH_4$ at atmospheric pressures. This data was reviewed in our last six month report at which time it was noted that some question existed about the numerical values of the activation energy. We are re-running these experiments to obtain more accurate values for the activation energy.

In our last report we reviewed some preliminary data on the use of dispersed catalysts for the ethylene plus oxygen to ethylene oxide reaction. These results were most promising but we noted that the observation of ethylene oxide at mass 44 is obscured by the presence of $CO_2$. To remove this ambiguity we reworked the gas chromatograph to allow it to operate in parallel with the mass spectrometer. This has consumed considerable time but we feel that the availability of two analysis techniques will justify the effort.

In the next six months we plan to investigate the CO, $CH_4$ and ethylene reactions in more detail with a view toward the determination of exoelectron-catalysis correlations.

One commercial application of this work has been discussed with the Dow Chemical Company (Texas Division). We hope to work out an arrangement whereby Dow will support some of the work in this area.

# REFERENCES


1. Jaeger, J. and N. Cook. Fundamental of Rock Mechanics, Methuen and Company, London, 1969.

2. Brown, J. and M. Singh. "Microseismic Activity of Rocks in Tension," Trans, AIME 238, No. 3, pg: 255-265, 1966.

3. Paul, W. Mining Lore, Morris Printing Company, Portland, Oregon, 1970.

4. Parkhomenko, E. Electrification Phenomena in Rocks, Plenum Press New York, 1971.

5. Weber, N. and M. Goldstein. "Stress Induced Migration and Partial Molar Volume of Sodium Ions in Glass," J. Chem. Phys. 41, No. 9, pg. 2898, 1964.

6. Brace, W. and A. Orange. "Electrical Resistivity Changes in Saturated Rock Under Stress," Science, 153, No. 3743, pg. 1525-6, 1966.

7. Wollbrandt, J., E. Linke and K. Meyer. "Emission of High Energy Electrons During Mechanical Treatment of Alkali Halides," Phys. Stat. Sol. (a) 27, pg. 153, 1975.

8. Harper, W. R. Contact and Frictional Electrification, Oxford, Clarendon Press, 1967.

9. Lewis, A. D., "Roaring Sands of the Kalahari Desert," South African Geographical Journal 19, pg. 33-49, 1936.

10. Lindsay, J. F., D. R. Criswell, T. L. Criswell, and B. S. Criswell, "Sound Producing Dune and Beach Sands," Submitted to the Geological Society of America, June 1974.

11. Criswell, D. R., J. F. Lindsay, and D. L. Reasoner. "Seismic and Acoustic Emissions of a Booming Dune," Submitted to the Journal of Geophysical Research.

## PERSONNEL

Students who have been supported by the grant and their present activities are listed below:

1. Donald Collins, M. S., 1963, Ph.D., California Institute of Technology, September 1969. Presently Research Associate, CIT.

2. George Rozgoni, Ph.D., 1963; Senior Staff Member, Bell Telephone Laboratories, Murray Hill, New Jersey.

3. Donald Creighton, Ph.D., 1964; Professor, University of Missouri, Rolla. (Partial NASA support.)

4. Col. C. W. Carlson, M.S., 1965; Active Duty, U. S. Army.

5. Melvin Eisenstadt, Ph.D., 1965; Professor of M. E., University of Puerto Rico, Mayaguez, P. R.

6. John Lane, M.S., 1968; Philco Ford Company, Tucson.

7. William Ott, M.S., 1970; Burr-Brown Research, Tucson. (Partial NASA support.)

8. Richard Pope, M.S., 1970; Hewlett-Packard Corp., Palo Alto, California.

9. Robert Goetz, M.S., 1972; North American Rockwell Corporation, Los Angeles, California.

10. Freedon Tamjidi, M.S., 1972; Field Engineer, Westinghouse Corporation.

## PUBLICATIONS GENERATED TO DATE BY RESEARCH ON THIS GRANT

S. A. Hoenig, et al

1. "Chemisorption Detector for Oxygen," Rev. Sci. Instr., 35, 15 (1964), with D. Collins.

2. "Protection of Copper in High Temperature Air," Rev. Sci. Instr., 35, 904 (1964).

3. "Chemisorption Detector for Hydrogen," Rev. Sci. Instr., 36, No. 1, 66 (1964), with M. Eisenstadt.

4. Change in the Thermionic Emission Current of Palladium Due to Chemisorption of Atomic and Molecular Hydrogen," J. Chem. Phys., 45, No. 1, 127-132 (July 1966), with M. Eisenstadt.

5. "Beam Source for Molecular and Atomic Hydrogen," Rev. Sci. Instr., 36, No. 12, 1878-1879 (1965), by M. Eisenstadt.

6. "Use of Liquid Nitrogen Cooled Shield to Protect a Proton Accelerator Against Oil Vapor Contamination," Rev. Sci. Instr., 37, No. 7, 977 (1966).

7. "A Low Cost, High Temperature (1300°C) Vacuum Furnace," J. Vacuum Sci. and Technology, 3, No. 6, 351 (1966).

8. "Detection of Hydrogen in Air by Means of Alkali Ion Current from Hot Palladium," Rev. Sci. Instr., Carlson and J. Abramowitz.

9. "Contamination of MOS Field Effect Transistors by Alkali Ions Emitted from Hot Tungsten or Molybdenum Filaments--Removal by Electric Fields," Elec. Communicator, 16-17, (November/December 1967).

10. "Polarization Sensitivity of the RCA 6903 Photocathode Tube." Applied Optics, 5, No. 6, 1091-1092 (1966), with A. Cutler.

11. "Chemisorption of Oxygen on Zinc Oxide--Effect of a DC Electric Field," Surface Sci., 11, 2 (1968), with J. Lane.

12. "The Electronic 'Sponge'--Selective Gas Adsorber," Indus. Research, (May 1968).

13. "Replication Versus Metallization for Interference Microscopy of Thin Films," J. Vacuum Sci. and Technology, 5, 125-126 (July/August 1968), with J. Lane.

14. "Ion and Electron Currents from Hot Filaments: Effects of Alloying on Electron Emission," Solid State Tech., 11, No. 12, 53 (December 1968), with R. Pope.

15. "A Study of Stress Corrosion Cracking of U-10% Mo Wires," in Applications of Field-Ion Microscopy in Physical Metallurgy and Corrosion, Edited by R. F. Hockman, et al., Geo. Instr. of Tech., Atlanta, (December 1969), with H. Sulsona.

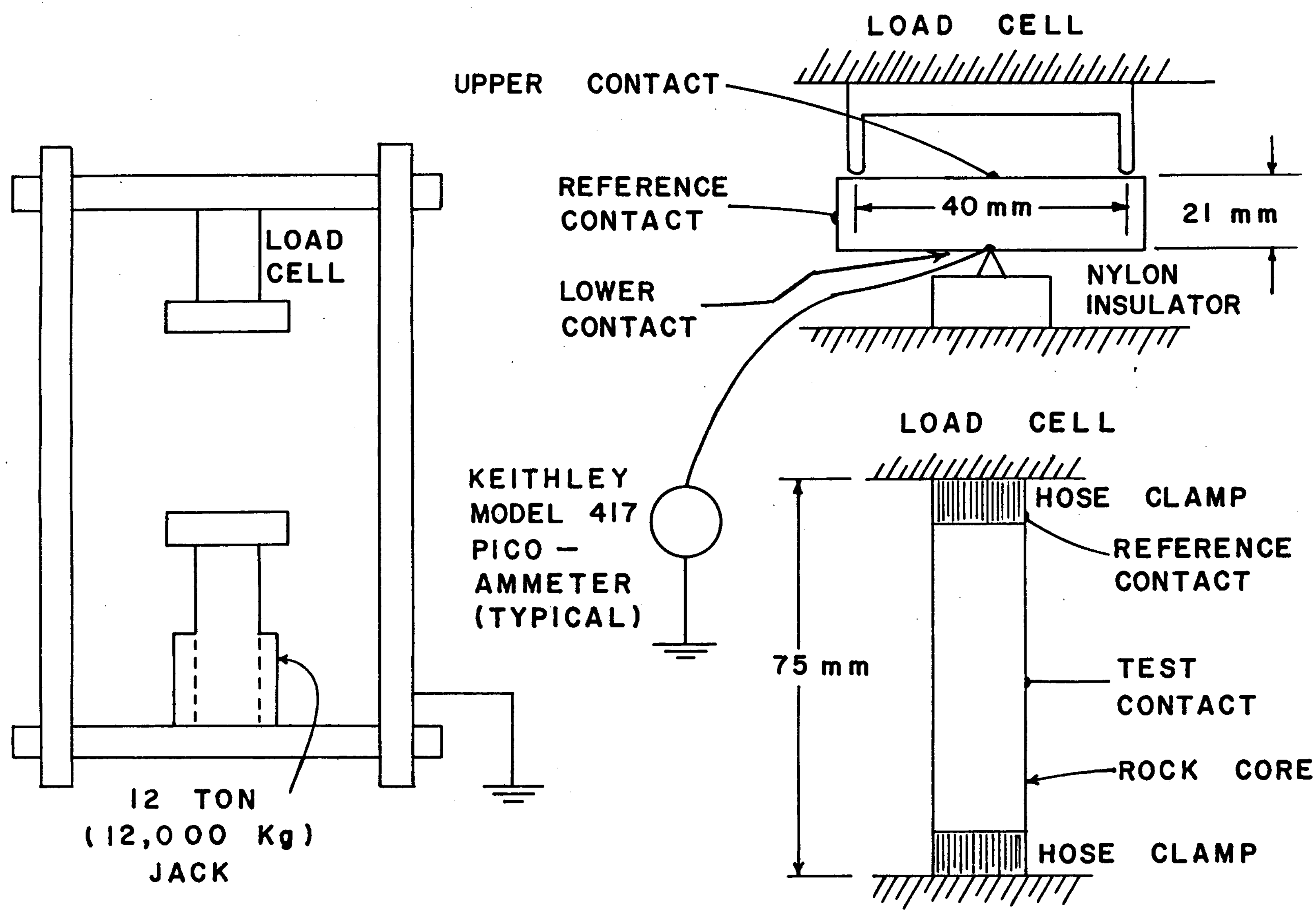
16. "Electron Emission During Heterogeneous Catalysis," (The Effect of External Electric Potentials), Journal of Catalysis, 28, No. 2, pg. 200 (1973), with Freedon Tamjidi.

17. "Applications of Exoelectron Emission to Nondestructive Evaluation of Fatigue, Crack Growth, and Annealing Process," ASTM STP 515, *Testing for Prediction of Material Performance in Structures and Components*, pg. 107-125 (1972).

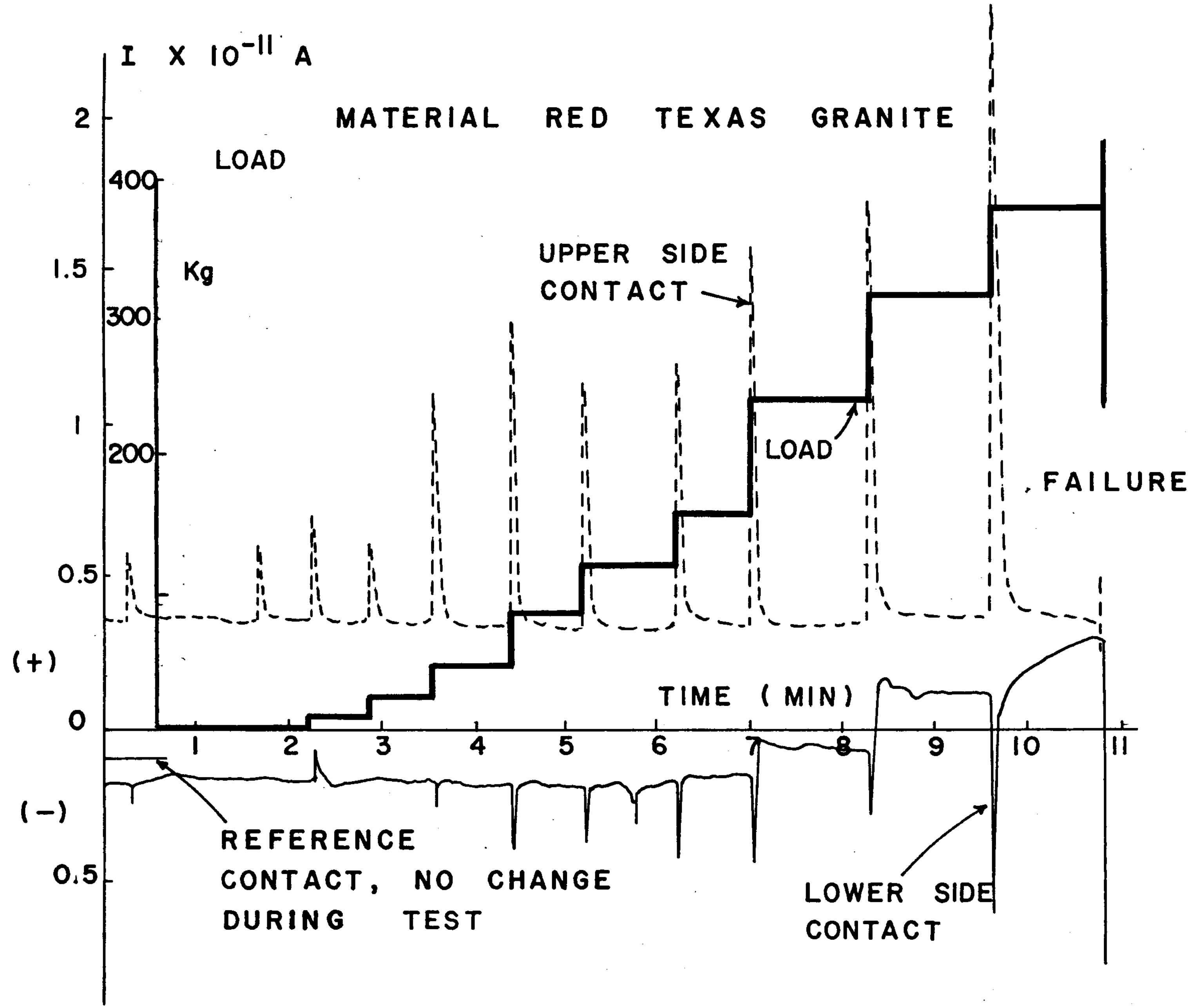
18. "Monitoring the Ball Milling Process by Means of Exoelectron Emission," Mining Congress Journal, 58, No. 11, Pg. 34-35 (1972).

19. "Monitoring Catalysts," Automotive Engineering, 81, No. 10, pg. 68, (1973).

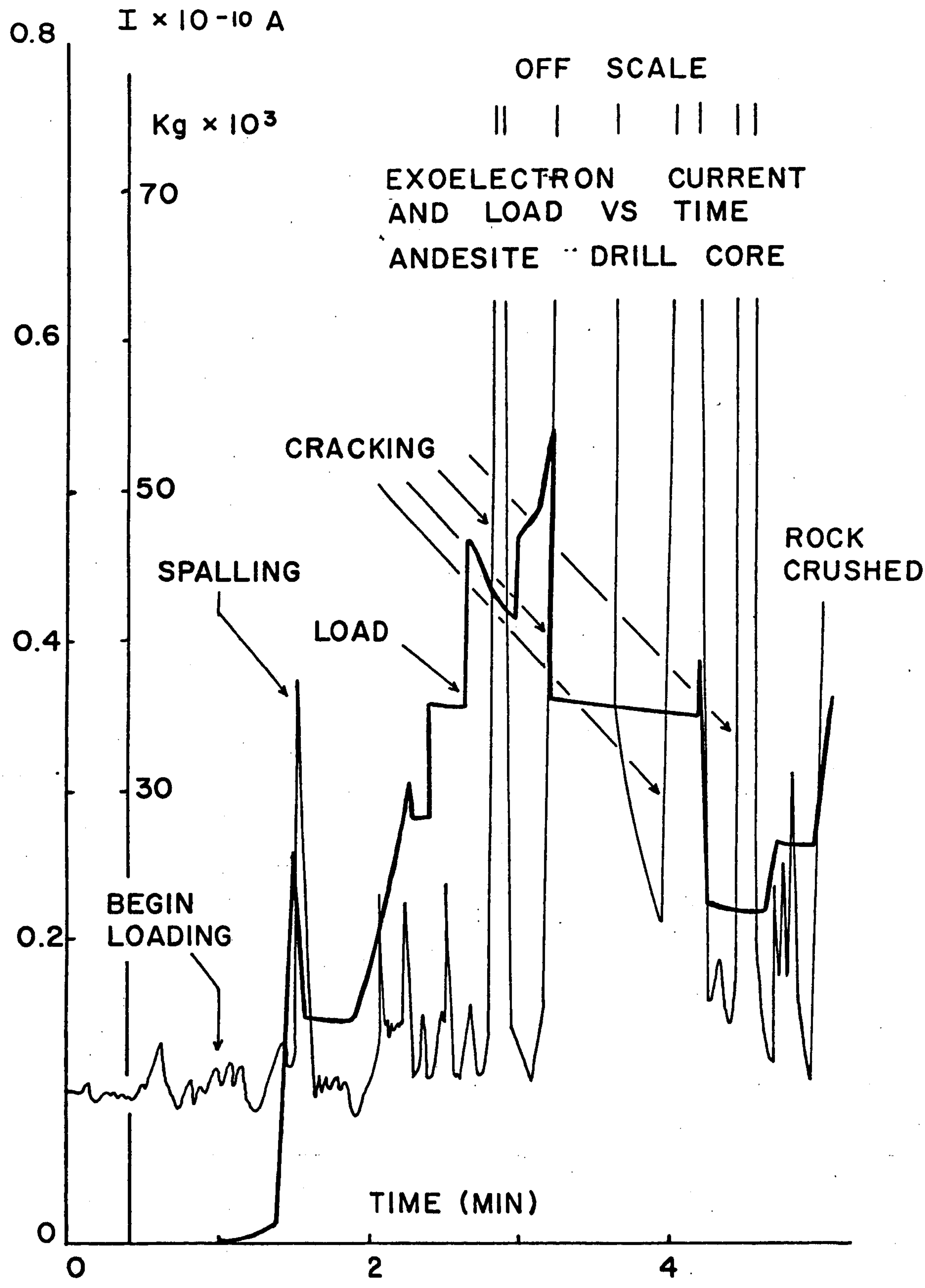
# LIST OF FIGURES


LOAD CELL
12 TON
(12,000 Kg)
JACK
UPPER CONTACT
REFERENCE CONTACT
LOWER CONTACT
LOAD CELL
40 mm
21 mm
NYLON INSULATOR
KEITHLEY MODEL 417 PICO — AMMETER (TYPICAL)
LOAD CELL
HOSE CLAMP
REFERENCE CONTACT
TEST CONTACT
ROCK CORE
HOSE CLAMP
75 mm

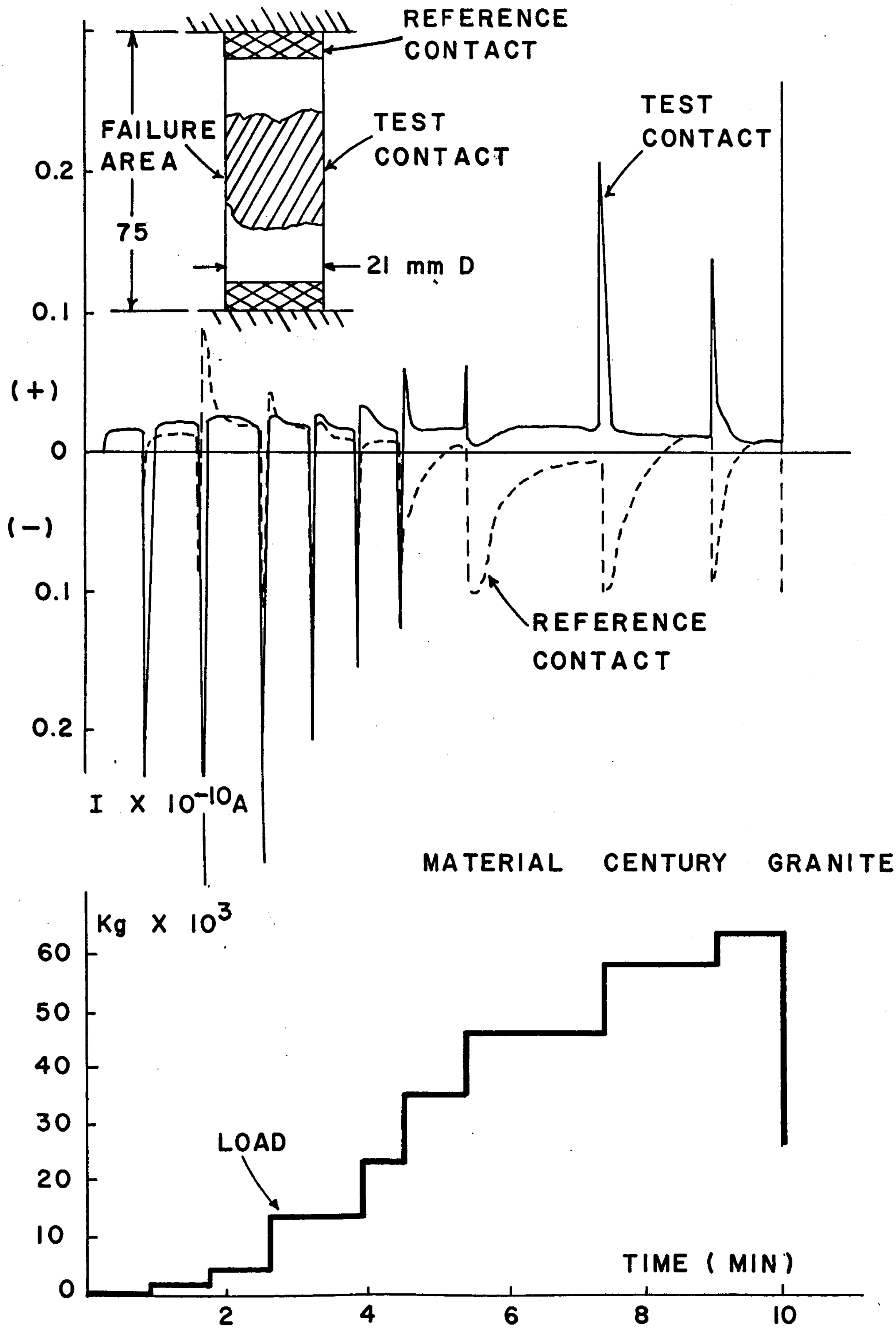
1

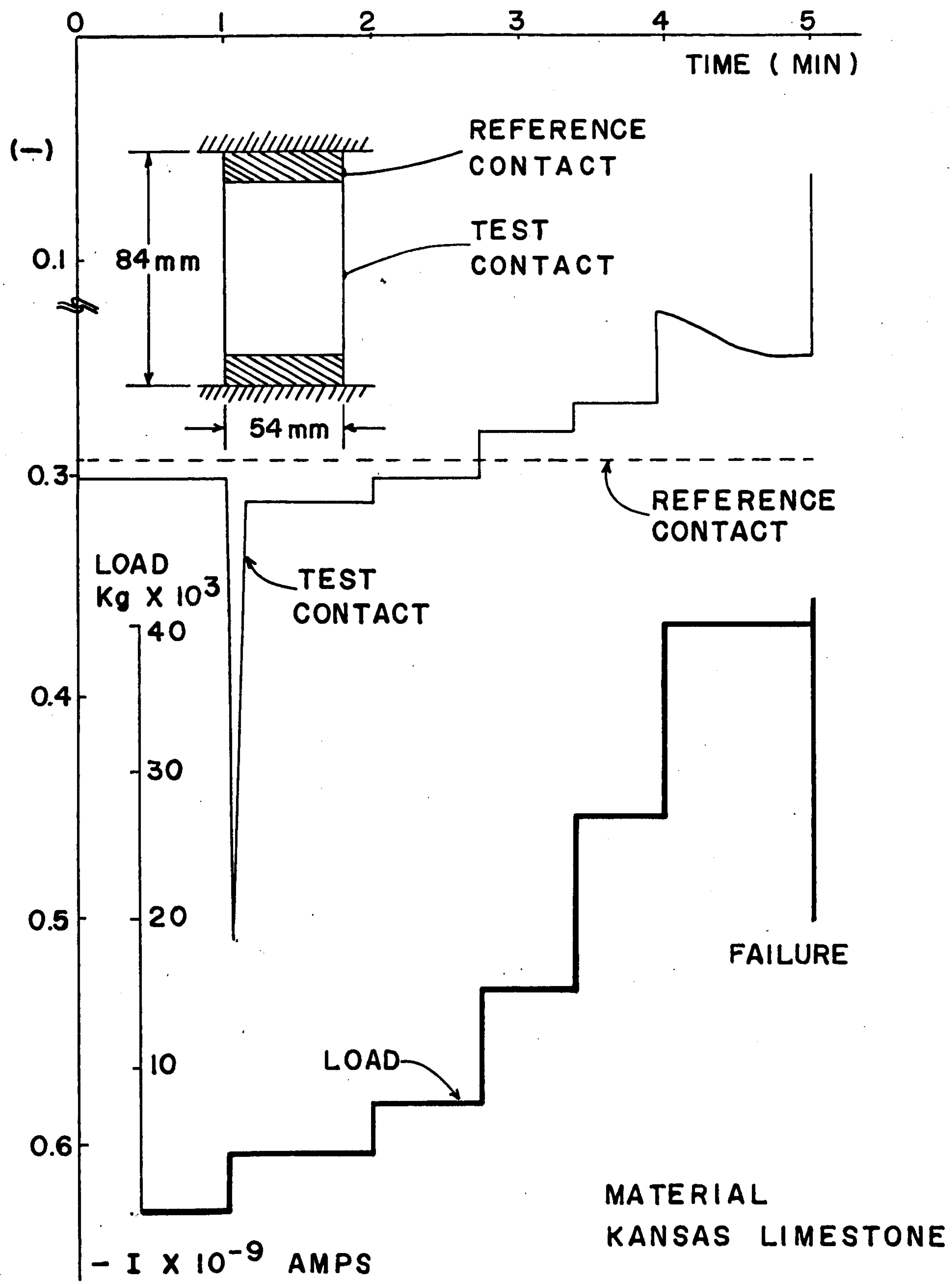

I X 10^-11 A
MATERIAL RED TEXAS GRANITE
LOAD
Kg
400
300
200
2
1.5
1
0.5
(+)
0
(-)
0.5
UPPER SIDE CONTACT
LOAD
FAILURE
TIME ( MIN)
1
2
3
4
5
6
7
8
9
10
11
REFERENCE CONTACT, NO CHANGE DURING TEST
LOWER SIDE CONTACT

(2)

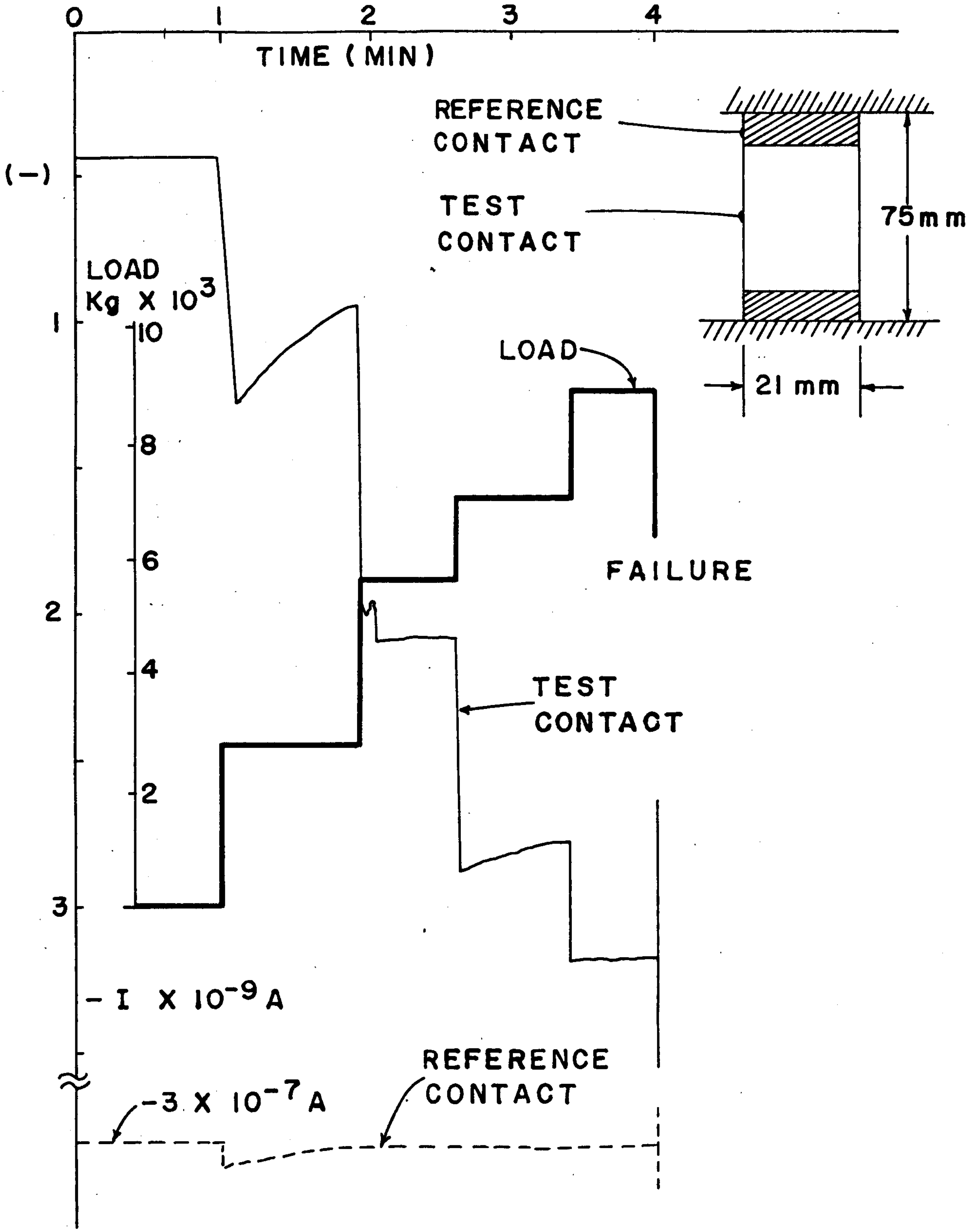

I × 10 -10 A
Kg × 10³
OFF SCALE
EXOELECTRON CURRENT AND LOAD VS TIME
ANDESITE DRILL CORE
CRACKING
SPALLING
LOAD
ROCK CRUSHED
BEGIN LOADING
TIME (MIN)
0.8
0.6
0.4
0.2
0
70
50
30
0
2
4

3

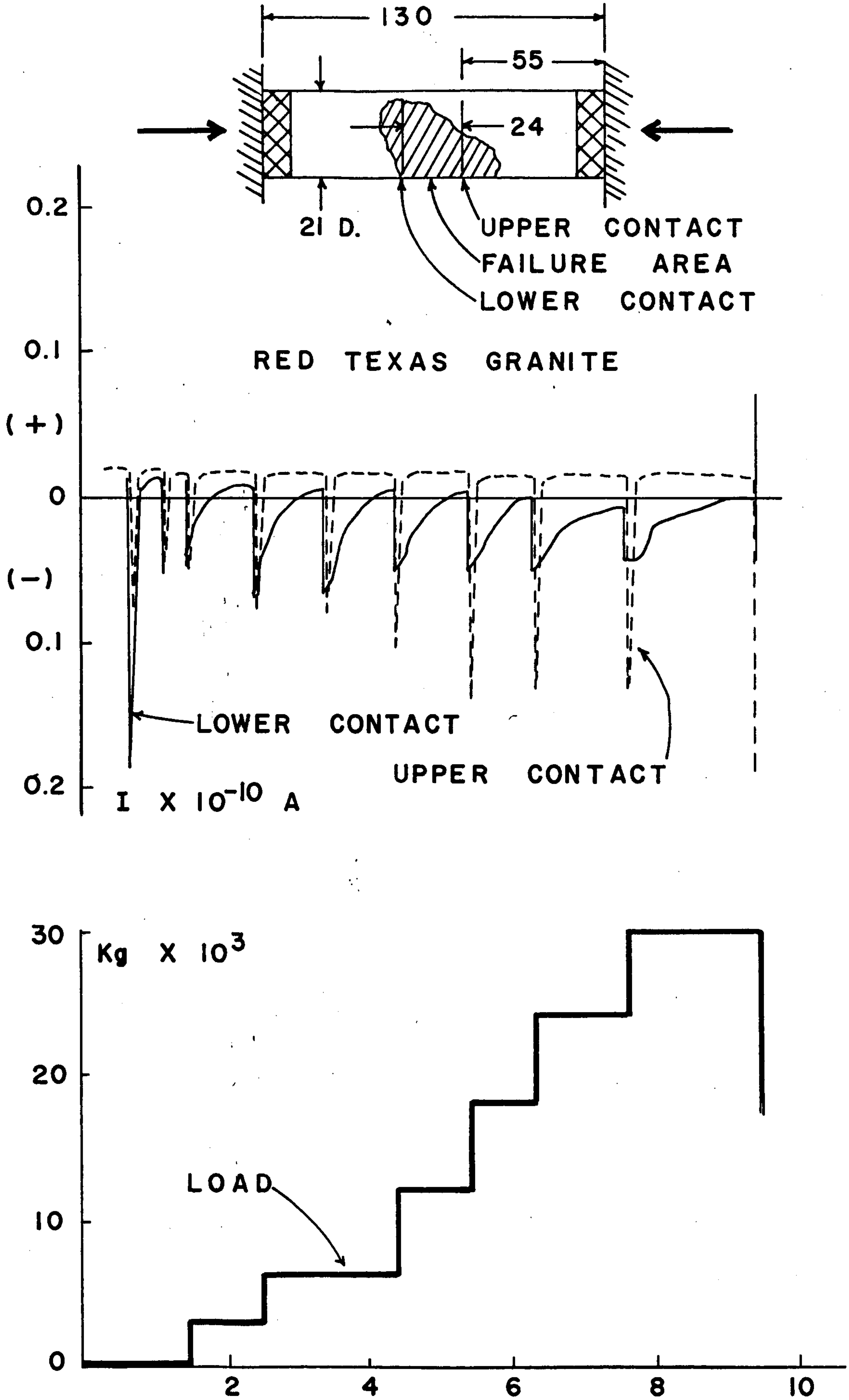

REFERENCE CONTACT
FAILURE AREA
TEST CONTACT
75
21 mm D
TEST CONTACT
0.2
0.1
(+)
0
(−)
0.1
0.2
REFERENCE CONTACT
I X 10^-10 A
MATERIAL CENTURY GRANITE
Kg X 10^3
60
50
40
30
20
10
0
LOAD
TIME (MIN)
2
4
6
8
10

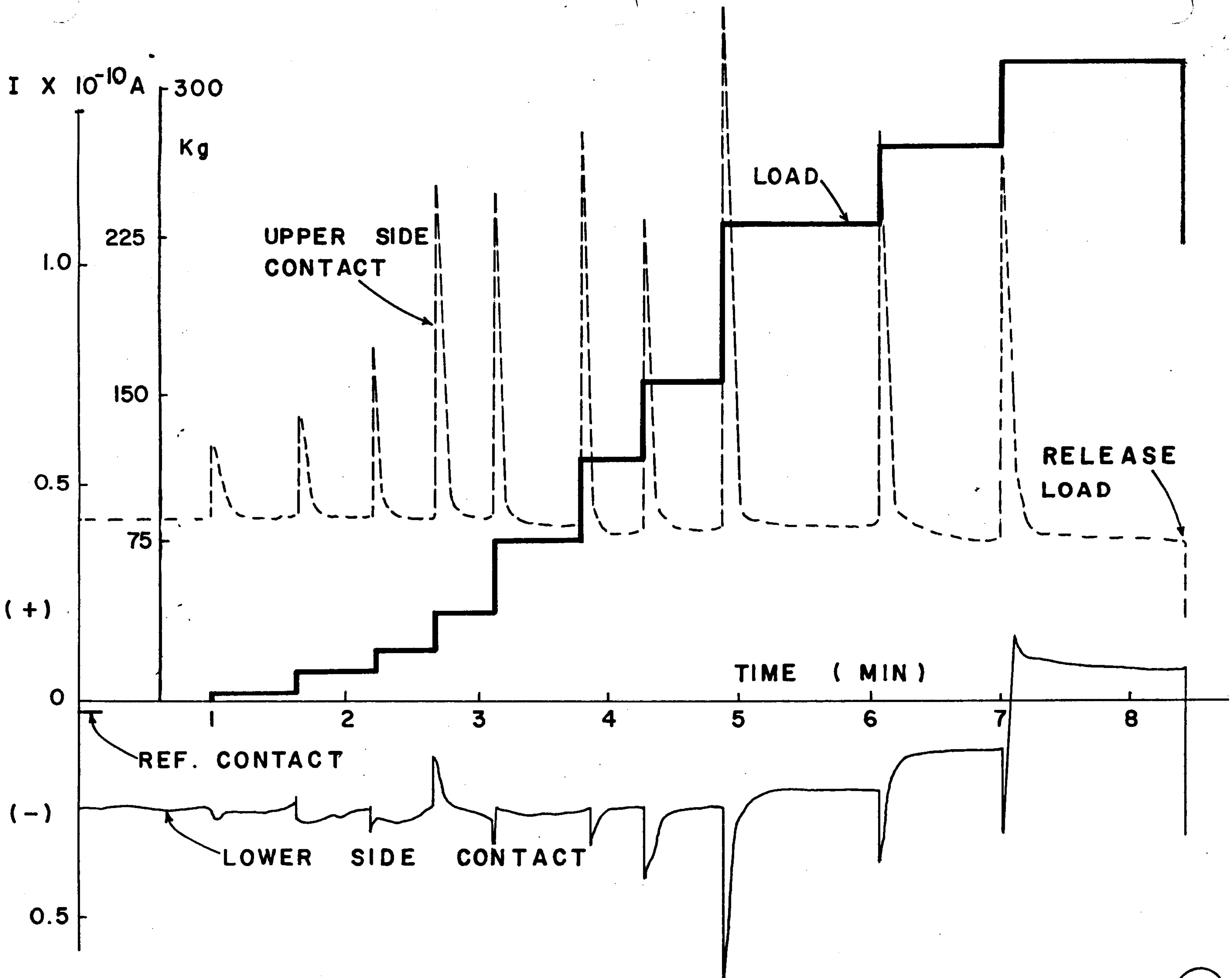


0
1
2
3
4
5
TIME ( MIN )
(−)
REFERENCE CONTACT
TEST CONTACT
84 mm
54 mm
0.1
0.3
0.4
0.5
0.6
REFERENCE CONTACT
LOAD Kg X 10$^3$
40
30
20
10
TEST CONTACT
FAILURE
LOAD
MATERIAL
KANSAS LIMESTONE
− I X 10$^{-9}$ AMPS



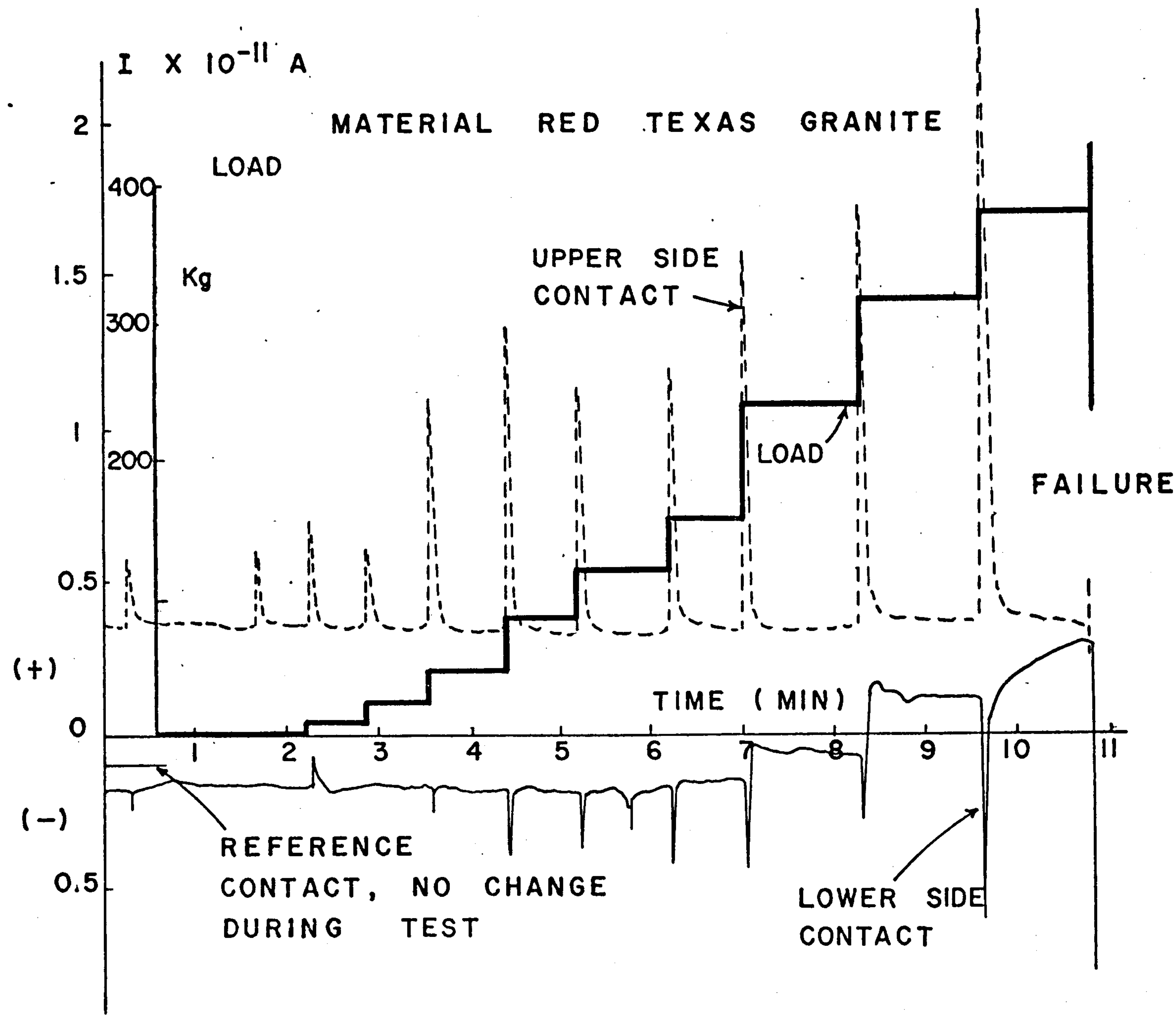

MATERIAL CEDAR CITY TONALITE


130
55
24
21 D.
UPPER CONTACT
FAILURE AREA
LOWER CONTACT
RED TEXAS GRANITE
0.2
0.1
(+)
0
(−)
0.1
0.2
LOWER CONTACT
UPPER CONTACT
I X 10^-10 A
30
20
10
0
Kg X 10^3
LOAD
2
4
6
8
10

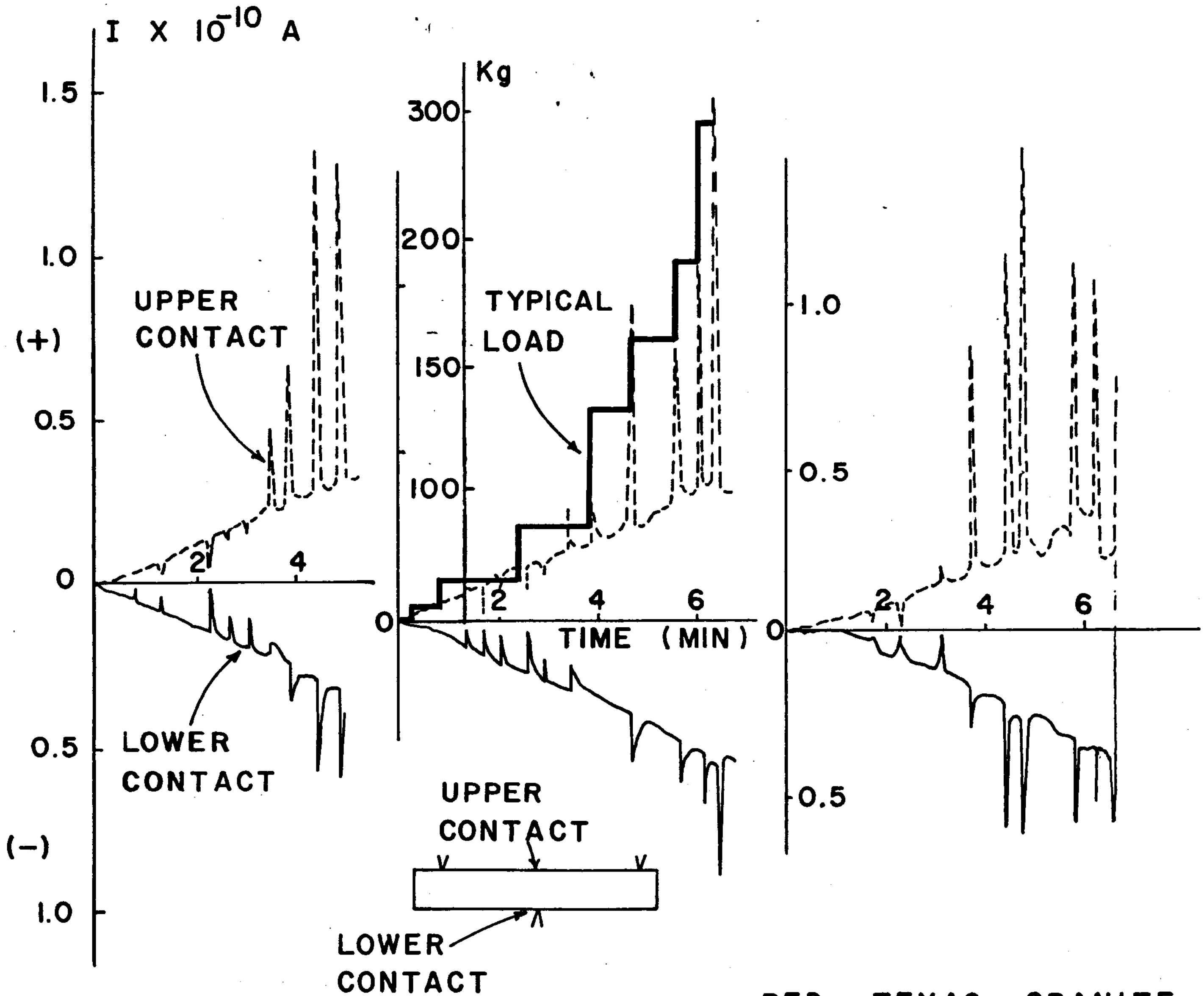



RED TEXAS GRANITE

8

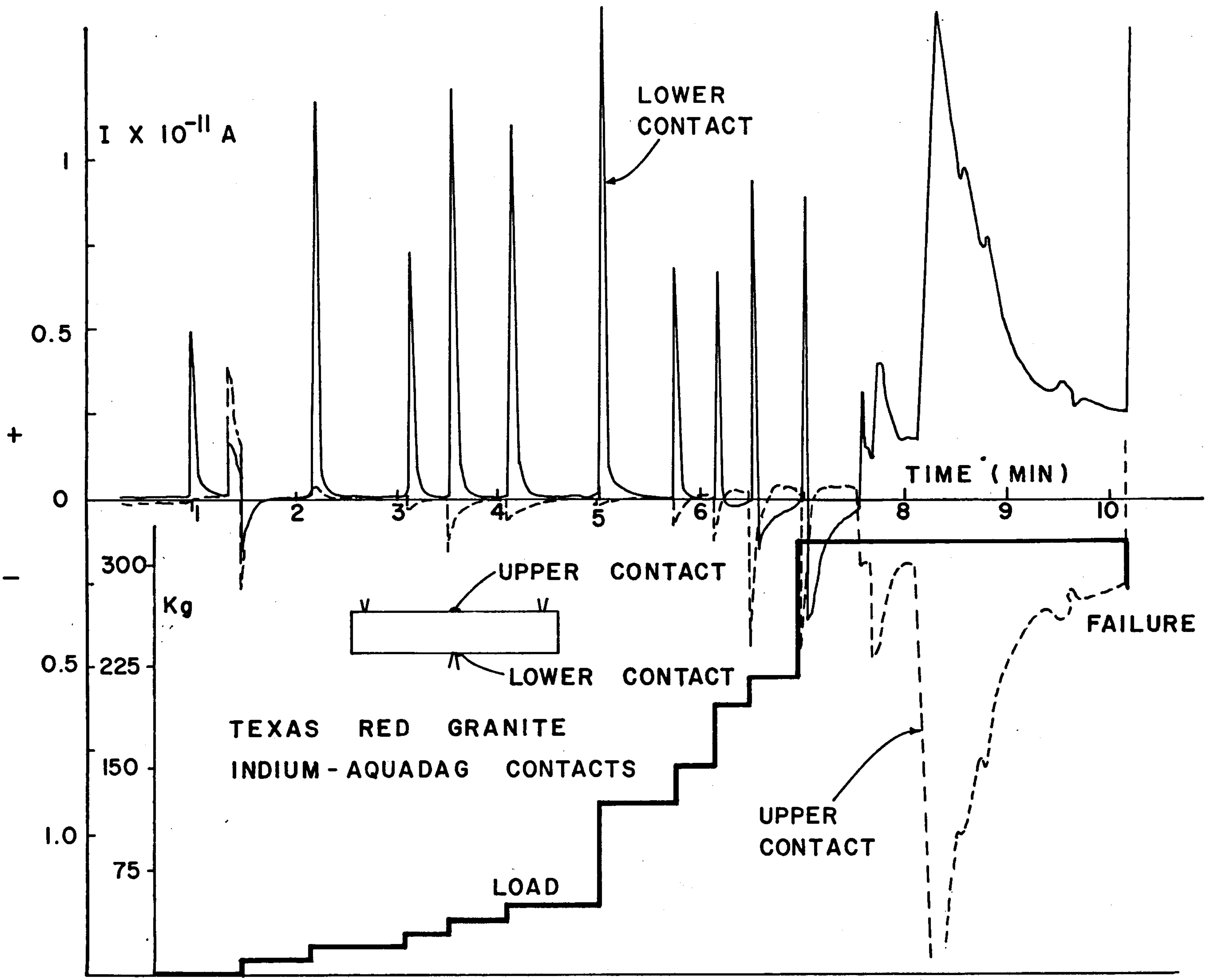


I X 10^-11 A
MATERIAL RED TEXAS GRANITE
LOAD
Kg
400
300
200
2
1.5
1
0.5
(+)
0
(−)
0.5
UPPER SIDE CONTACT
LOAD
FAILURE
TIME (MIN)
1
2
3
4
5
6
7
8
9
10
11
REFERENCE CONTACT, NO CHANGE DURING TEST
LOWER SIDE CONTACT

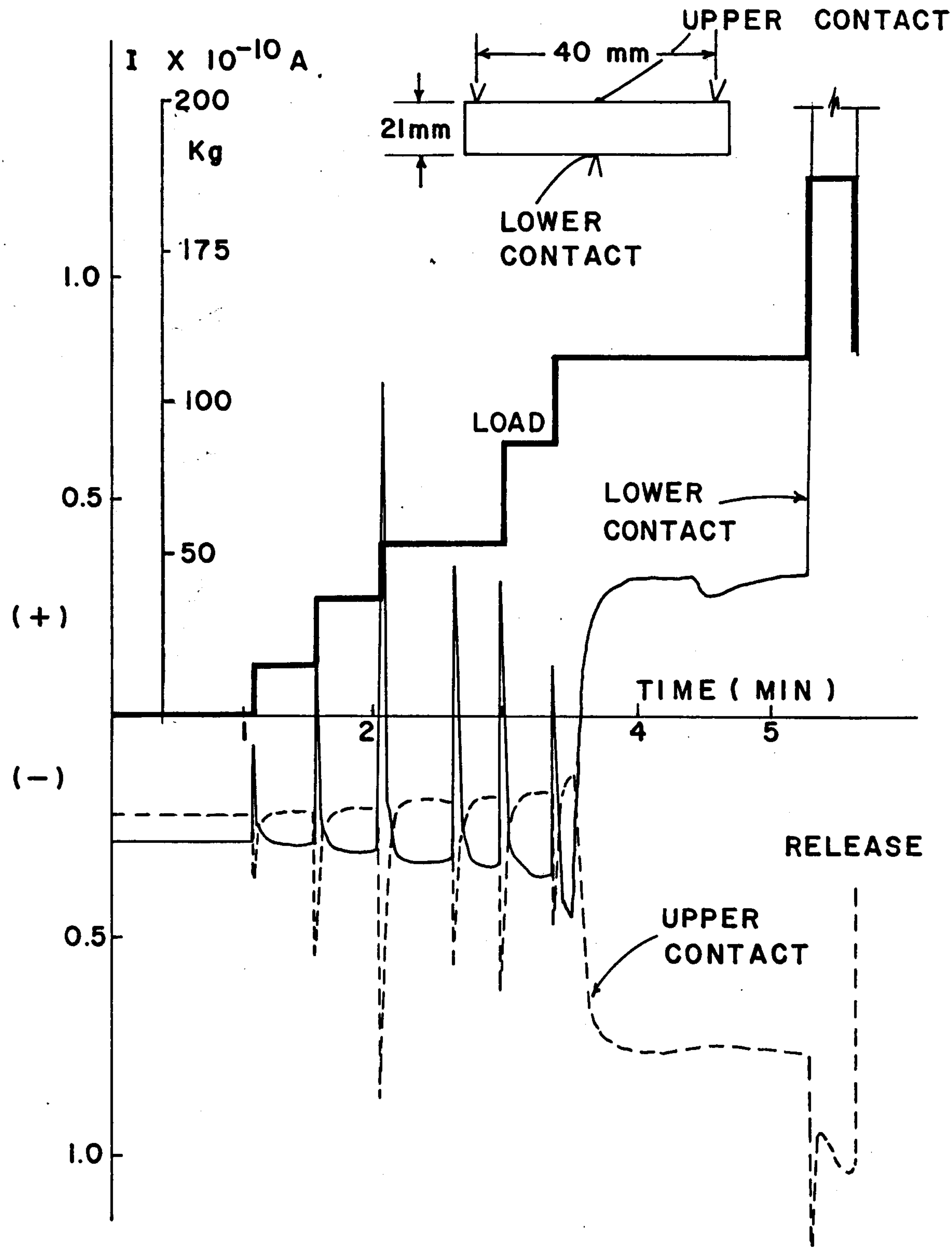



RED TEXAS GRANITE

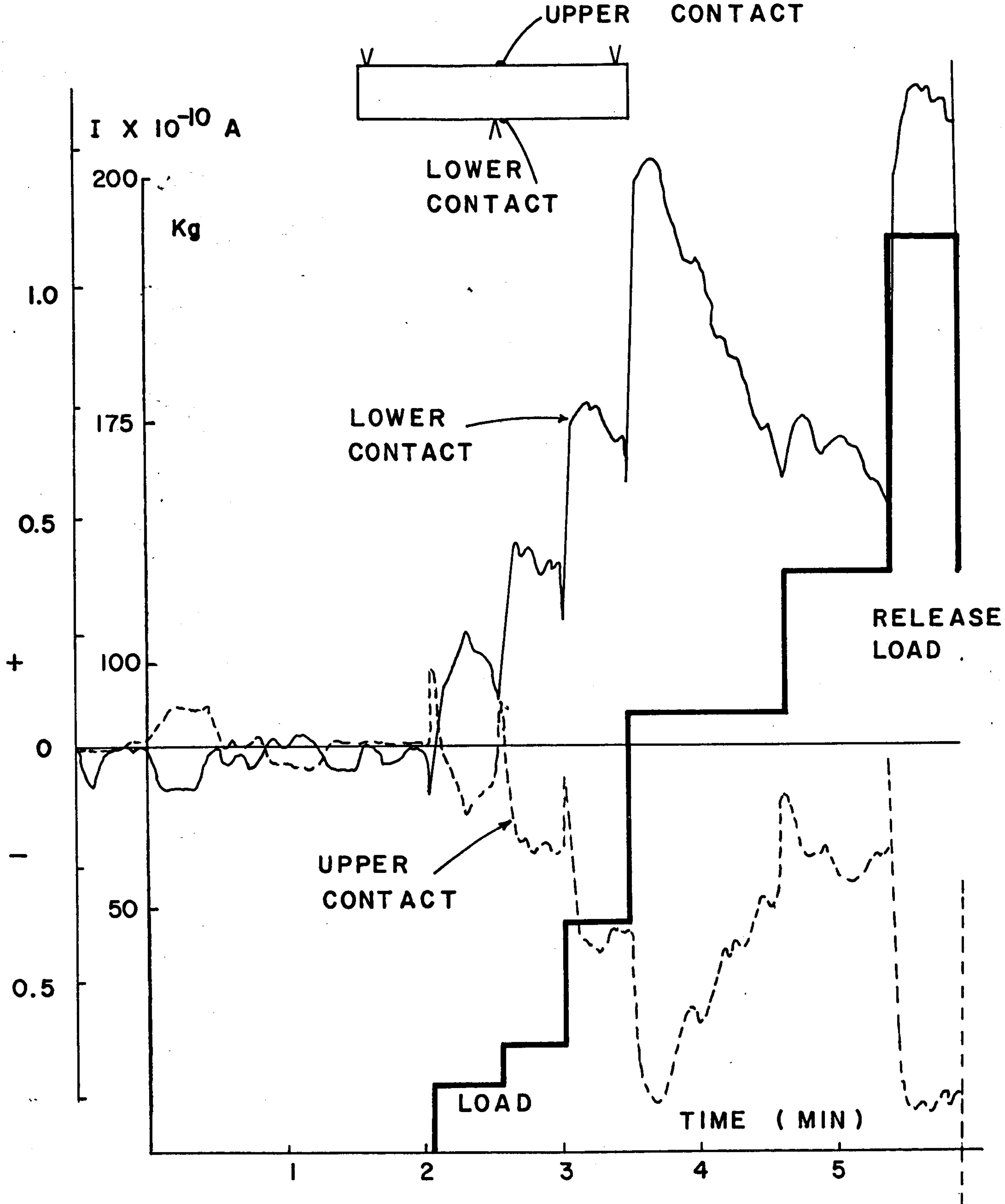
(10)


I X $10^{-11}$ A
1
0.5
+
0
-
0.5
1.0
Kg
300
225
150
75
TIME (MIN)
1
2
3
4
5
6
8
9
10
LOWER CONTACT
UPPER CONTACT
LOWER CONTACT
TEXAS RED GRANITE
INDIUM - AQUADAG CONTACTS
LOAD
UPPER CONTACT
FAILURE

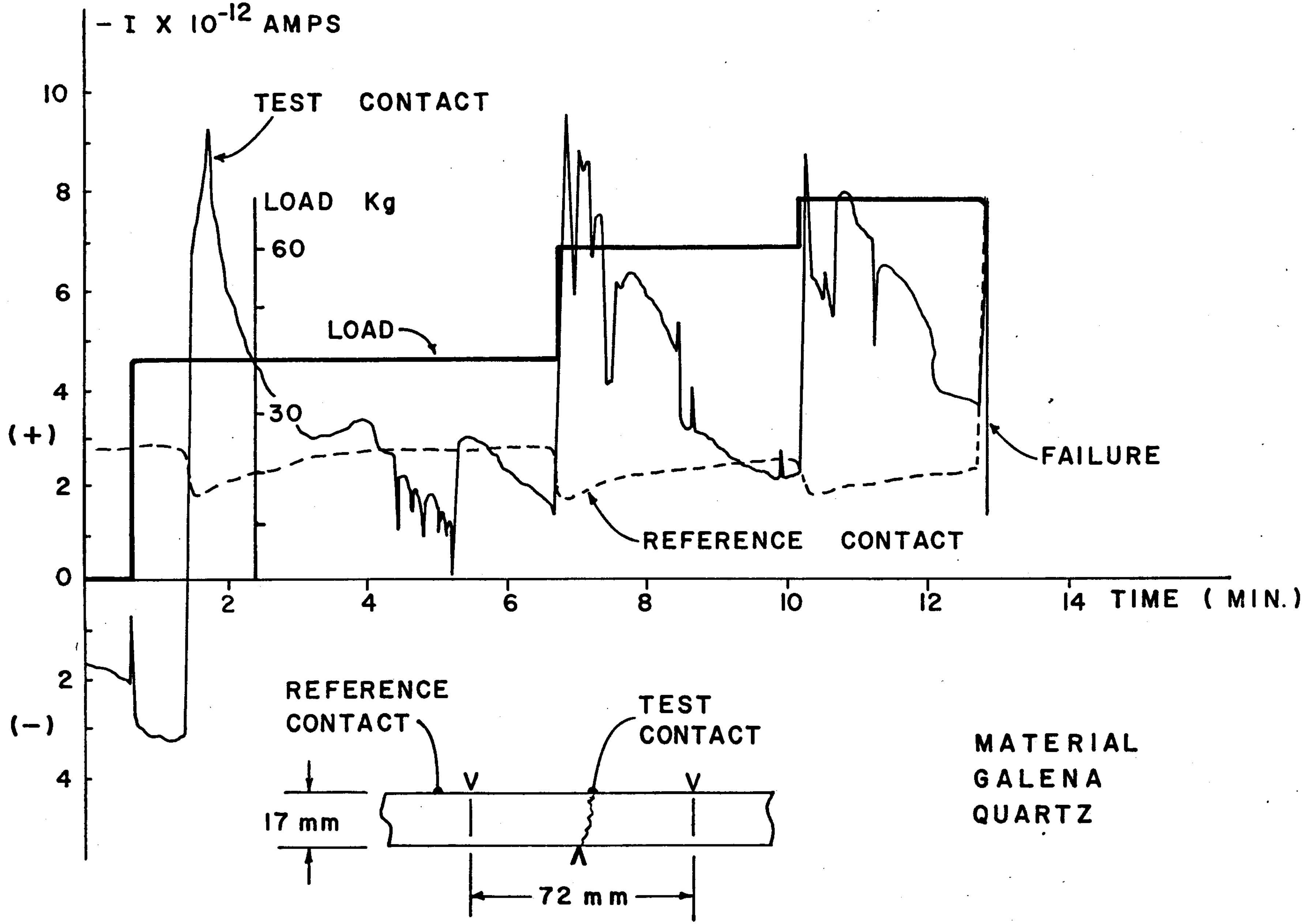
12



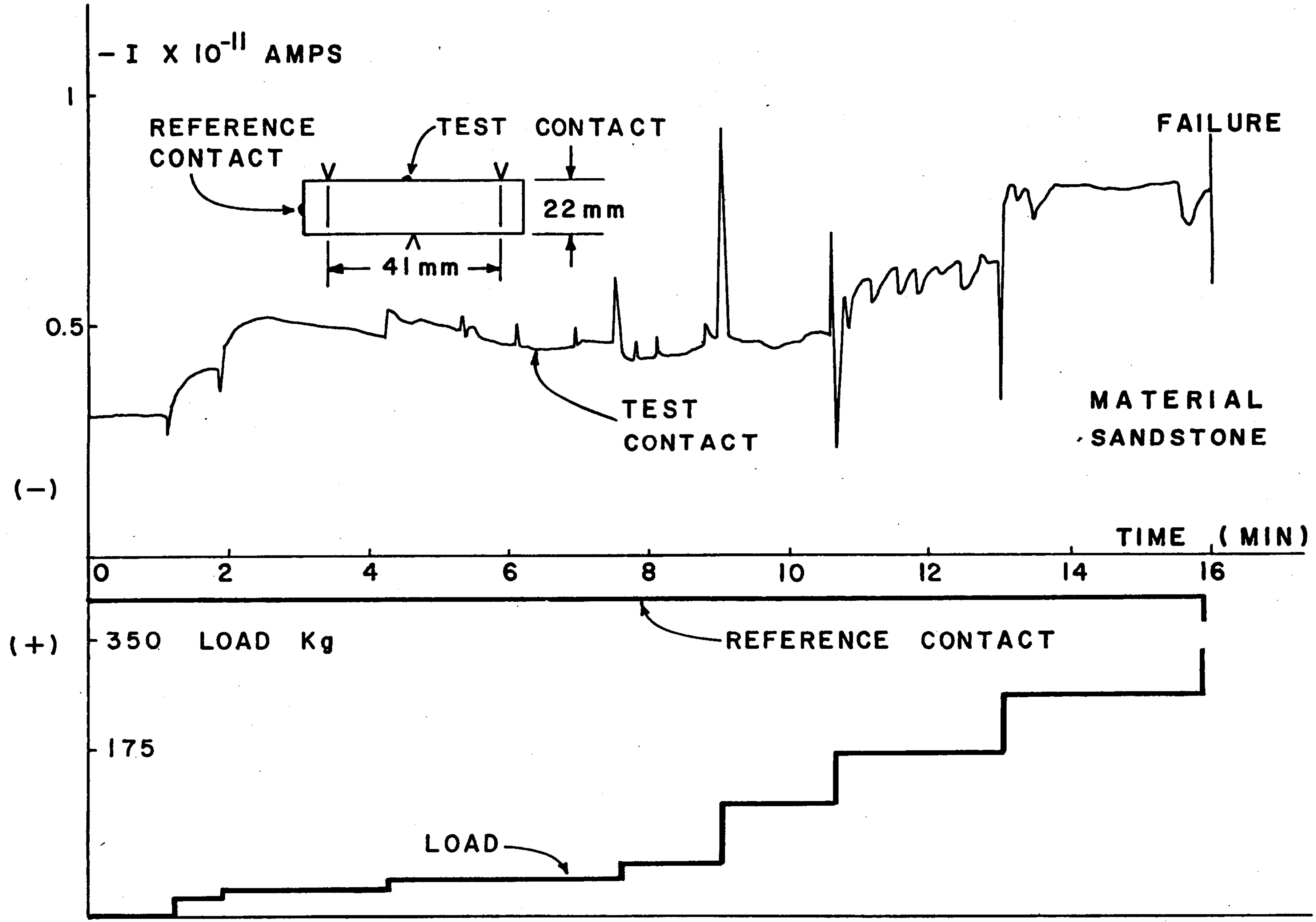

TEXAS RED GRANITE DRILLED PIN
CONNECTIONS ONLY




RED TEXAS GRANITE INDUM-AQUADAG CONTACTS, 100 HOUR SOAK IN DISTILLED WATER BEFORE TESTING

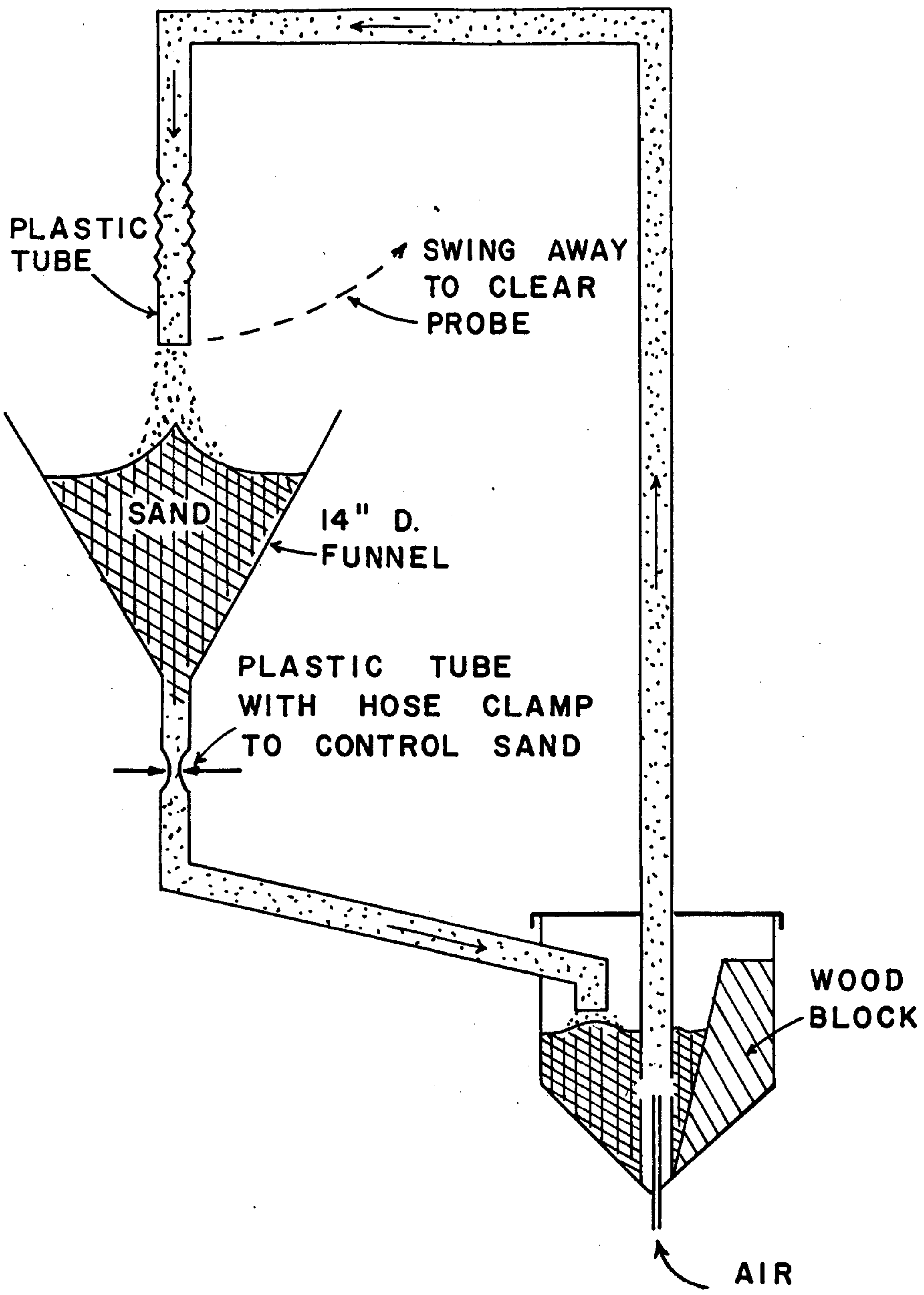


- I X $10^{-12}$ AMPS
10
8
6
4
(+)
2
0
2
(−)
4
TEST CONTACT
LOAD Kg
60
30
LOAD
FAILURE
REFERENCE CONTACT
2
4
6
8
10
12
14
TIME (MIN.)
REFERENCE CONTACT
TEST CONTACT
17 mm
72 mm
MATERIAL
GALENA
QUARTZ

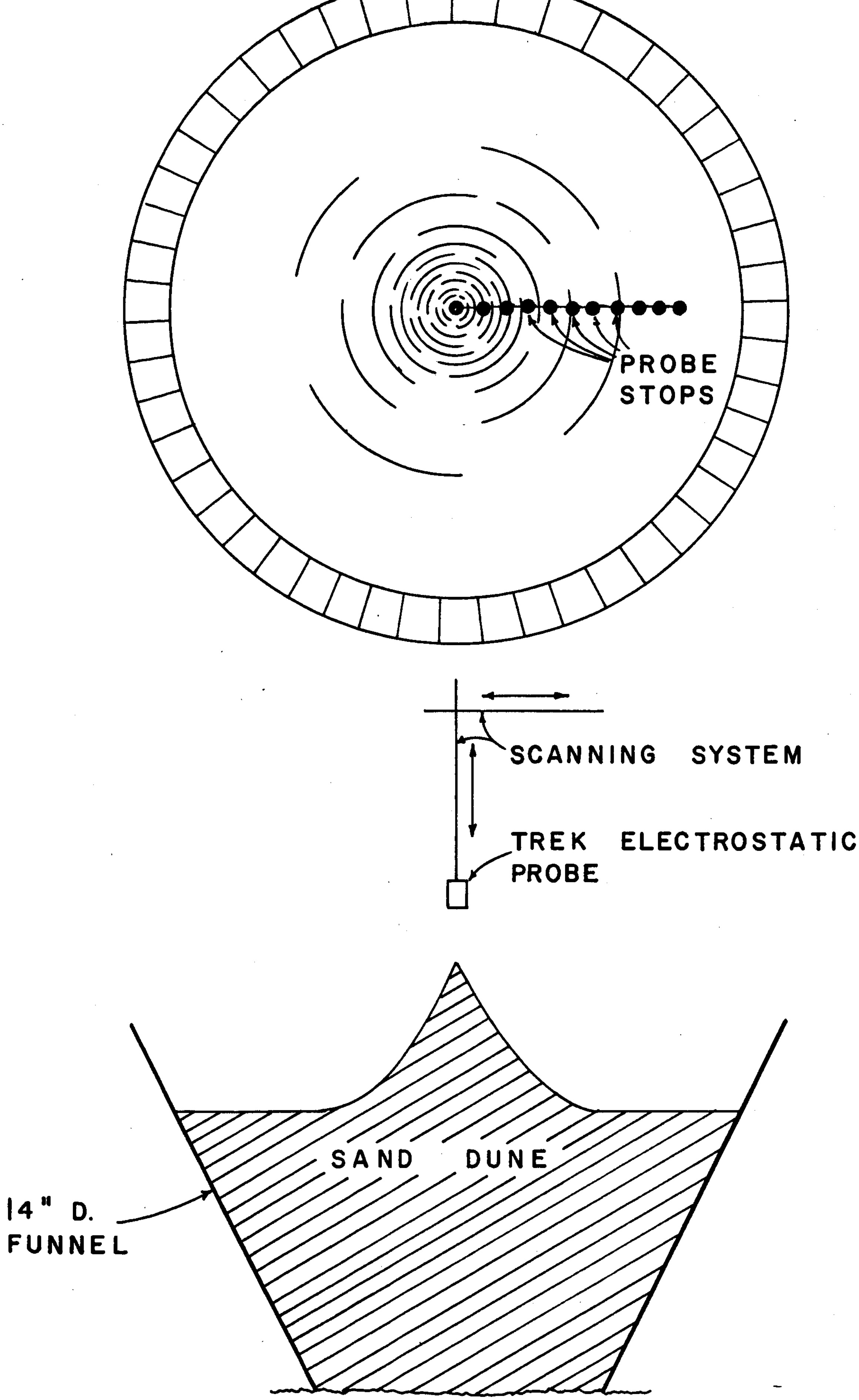


- I X 10^-11 AMPS
1
0.5
(−)
(+)
REFERENCE
CONTACT
TEST CONTACT
22 mm
41 mm
TEST
CONTACT
FAILURE
MATERIAL
SANDSTONE
TIME (MIN)
0
2
4
6
8
10
12
14
16
350 LOAD Kg
175
REFERENCE CONTACT
LOAD

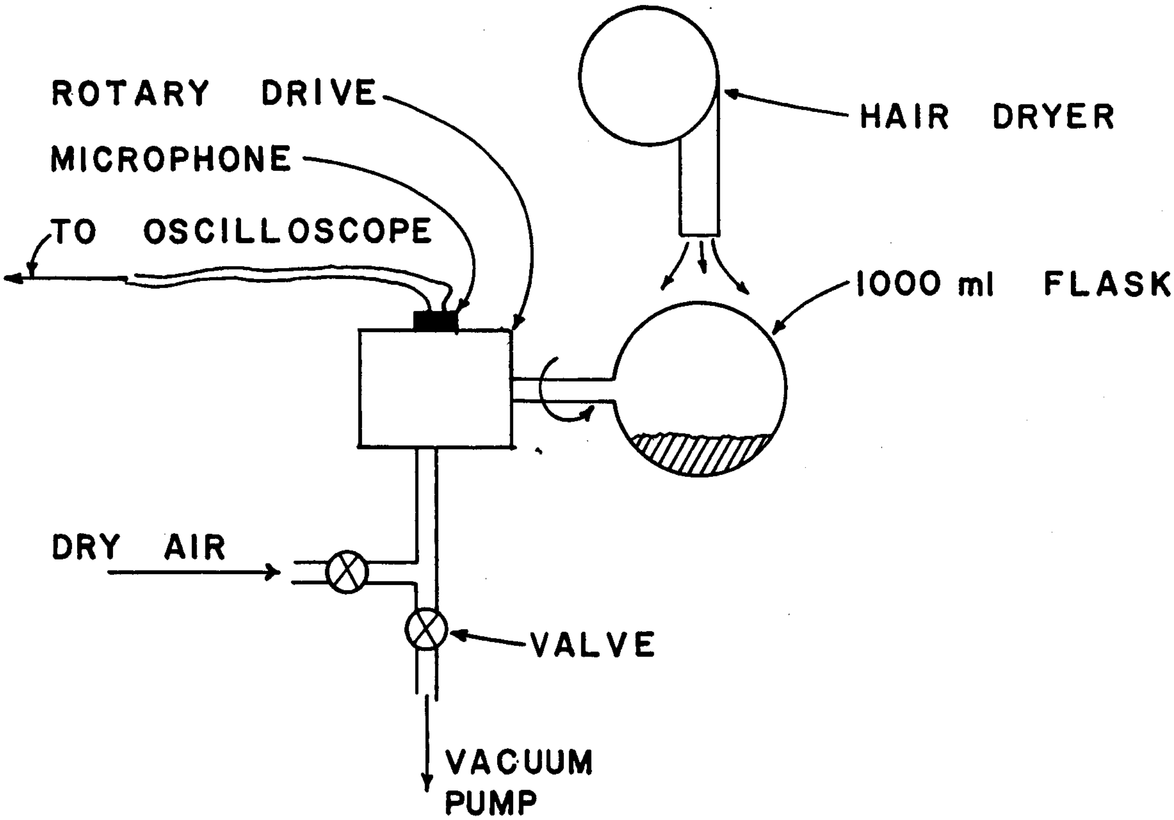

16

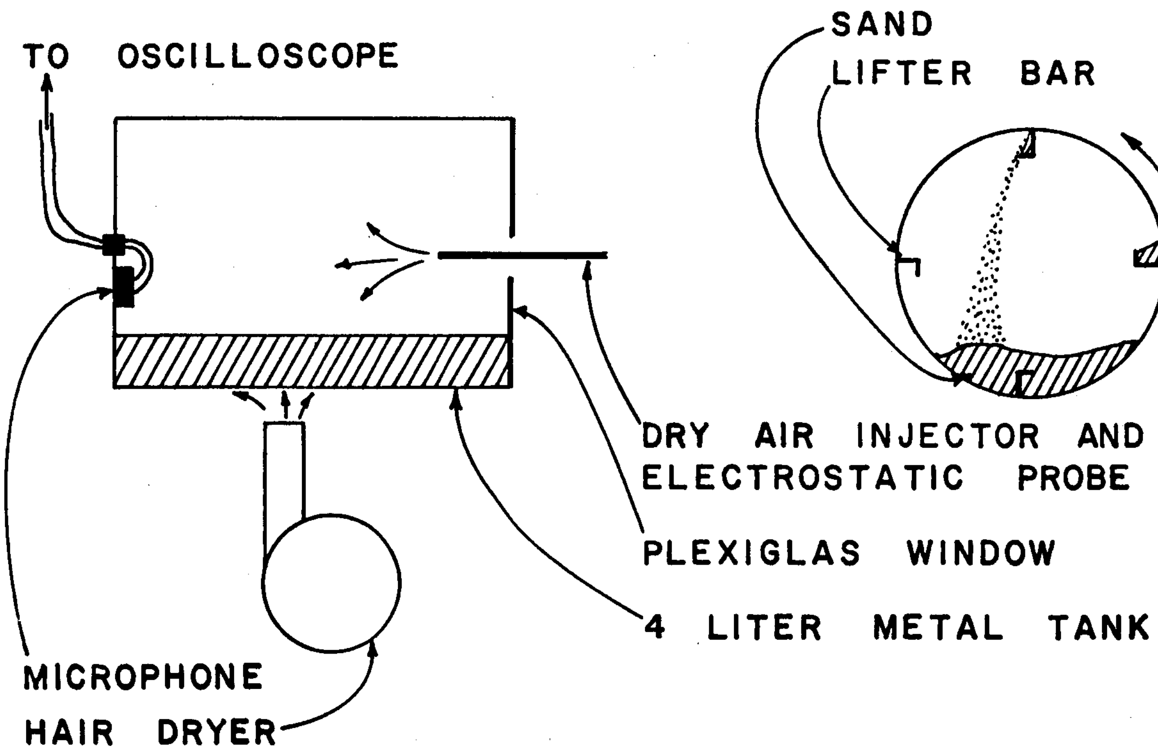



SAND DUNE GROWTH SYSTEM
( SCALE , NONE )




SAND DUNE PROBE SYSTEM




LABORATORY SYSTEMS FOR BOOM SAND STUDIES